RI 9388

REPORT OF INVESTIGATIONS/1991

Time Effects on Resin-Grouted Bolt Anchorage Characteristics

By William J. Wuest and Raymond M. Stateham

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Report of Investigations 9388

Time Effects on Resin-Grouted Bolt Anchorage Characteristics

By William J. Wuest and Raymond M. Stateham

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

Wuest, William J.

Time effects on resin-grouted bolt anchorage characteristics / by William J. Wuest and Raymond M. Stateham.

p. cm. — (Report of investigations; 9388)

Includes bibliographical references (p. 10).

Supt. of Docs. no.: I 28.23:9388.

1. Mine roof bolts, Resin—Testing. 2. Anchorage (Structural engineering). I. Stateham, Raymond M. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9388.

TN23.U43 [TN289.3] 622 s—dc20 [622'.28] 90-2272 CIP

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to Units of the International System of Units (SI)

Abbreviation	Unit of measure	To convert to—	Multiply by—
ft	foot	meters	0.30
in	inch	centimeters	2.54
	kip	kilonewtons	4.45
kip/in	kip per inch	kilonewtons per centimeter	1.75
lbf	pound (force)	newtons	4.45
lb/ft^3	pound per cubic foot	kilograms per cubic meter	16.0
lb/in^2	pound per square inch	newtons per square centimeter	.69

TIME EFFECTS ON RESIN-GROUTED BOLT ANCHORAGE CHARACTERISTICS

By William J. Wuest[1] and Raymond M. Stateham[2]

ABSTRACT

The technical analysis of parameters that can influence roof and rib reinforcement is important to the operation of safe and profitable underground mines. One such parameter, studied in this U.S. Bureau of Mines investigation, is the effect of time on untensioned, resin-grouted bolt anchorage characteristics. A group of seventy-three 4-ft-long bolts with three different grout column lengths were installed in a stable coal mine roof. The bolts were then subjected to standardized pull tests at various intervals throughout a 37-month period. For each test, load-deformation data were reduced to determine axial stiffness and yield point. The magnitudes of these two anchorage characteristics at the time of installation were compared with results from subsequent pull tests to determine if anchorage capacity deteriorated. Bolts with 18-in grout columns were studied over 9 months, and no measurable loss occurred. Bolts with 48- and 24-in grout columns were studied over 37 months and also exhibited no measurable loss.

[1]Mining engineer.
[2]Supervisory geophysicist (retired).
Denver Research Center, U.S. Bureau of Mines, Denver, CO.

INTRODUCTION

Roof bolting is an important element of many coal mine ground control systems throughout the world. Depending on the mining method, it is also widely used in metal and nonmetal operations. It has been estimated that 85 million bolts were installed by the U.S. coal industry in 1988, and about half were grouted with polyester resin (*1*).[3] Despite this widespread application, there is limited information available to researchers, mine operators, and safety officials with respect to the effects of time on anchorage characteristics.

Roof bolting became popular in U.S. coal mines in the 1950's. Because little was known at that time about tensioned bolt reinforcement mechanics, several organizations undertook research investigations (*2-3*). With the advent of untensioned grouted bolts around 1969, additional investigations were made to evaluate reinforcement mechanisms further (*4-6*). These studies were completed during relatively short intervals, however, and time was not considered an influencing parameter.

The amount of time a bolt should provide structural reinforcement to the underground workings after being installed in a mine opening varies greatly. For a coal mine room-and-pillar section being mined, the bolts are often required to provide 6- to 18-months service. If the bolts are used in a main entry, 20- to 30-years service may be necessary. During this service life, there are a number of parameters that can influence reinforcement capability: rock properties, in situ stress, geologic structure, ground water, grout degeneration, air humidity, and mining method.

For these reasons, personnel from the U.S. Bureau of Mines participated in a cooperative research project with a west-central Colorado coal mine. The Bureau conducted this study as part of its ongoing effort to improve ground control techniques and to enhance mine safety.

ACKNOWLEDGMENTS

The authors thank the management and personnel of Powderhorn Coal Co.'s Roadside Mine, Palisade, CO, for providing an underground field site to conduct this investigation.

GENERAL CONSIDERATIONS

BRIEF DESCRIPTION OF RESIN-GROUTED BOLT REINFORCEMENT MECHANICS

Since becoming popular in the 1970's, the use of untensioned, resin-grouted bolts has proven successful in a diverse range of ground conditions (*7*). Untensioned bolting systems are considered a passive form of mine roof reinforcement (*8*). Other than upward thrust applied by the installation equipment, no load is placed on the bolts, and until the rock mass begins to shift after being excavated, no reinforcement is provided. In contrast, when a tensioned bolt is installed, an active load is applied that clamps the immediate roof, generating a zone of compression several feet thick (*8*).

Prevalent theory suggests that resin-grouted bolts provide ground support by the action of one or more of three basic mechanisms: (1) suspending detached rock to stable top, (2) binding the rock mass together, and (3) providing shear resistance along failure surfaces (fig. 1). Suspension results when a separation in the roof develops and a rock load hangs from the portion of bolt

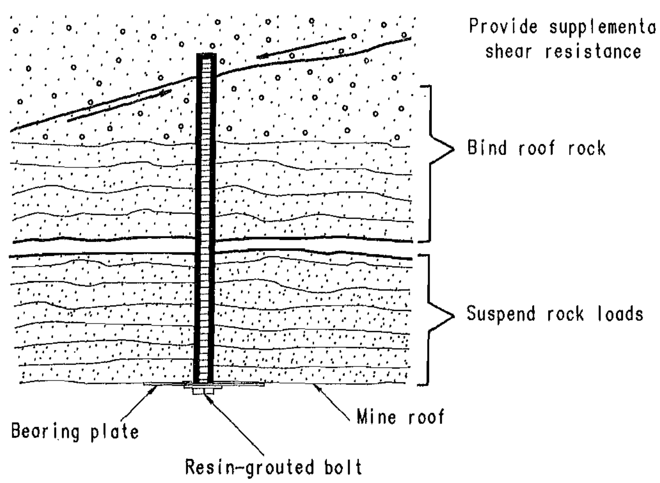

Figure 1.—Resin-grouted bolt reinforcement mechanisms.

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

that is securely anchored. Binding holds rock layers and blocks together, preventing separation. Supplemental rock-on-rock shear resistance is provided when the roof sags and bedding planes move laterally across each other, or movement occurs along other failure surfaces such as slips, joints, and faults. These three reinforcement mechanisms can act alone or together. From mine to mine and section to section, as the nature of ground conditions change, the proportion of reinforcement each mechanism provides will vary.

ROOF-BOLT ANCHORAGE CHARACTERISTICS

The common method of measuring anchorage characteristics of an in situ roof bolt is to apply an increasing axial-tensile force at the bolt head and to measure deformation as force increases. This is accomplished by the standardized pull test.

Recommended procedures for conducting a pull test are outlined by the International Society for Rock Mechanics (*9*). To summarize, a hydraulic ram is attached to a pull collar on the bottom of the bolt. When the ram is pressurized, an upward force is applied to the mine roof through the bearing plate, and a downward force is applied to the bolt head through the pull collar. Initially, 1,000 lbf is placed on the ram to take up slack in the testing equipment. The force is then increased at 1,000-lbf increments until the bolt, grout, or surrounding rock yields. System deformation is measured at each increment with a dial gauge extensometer or linear variable differential transducer. The testing equipment is shown in figure 2.

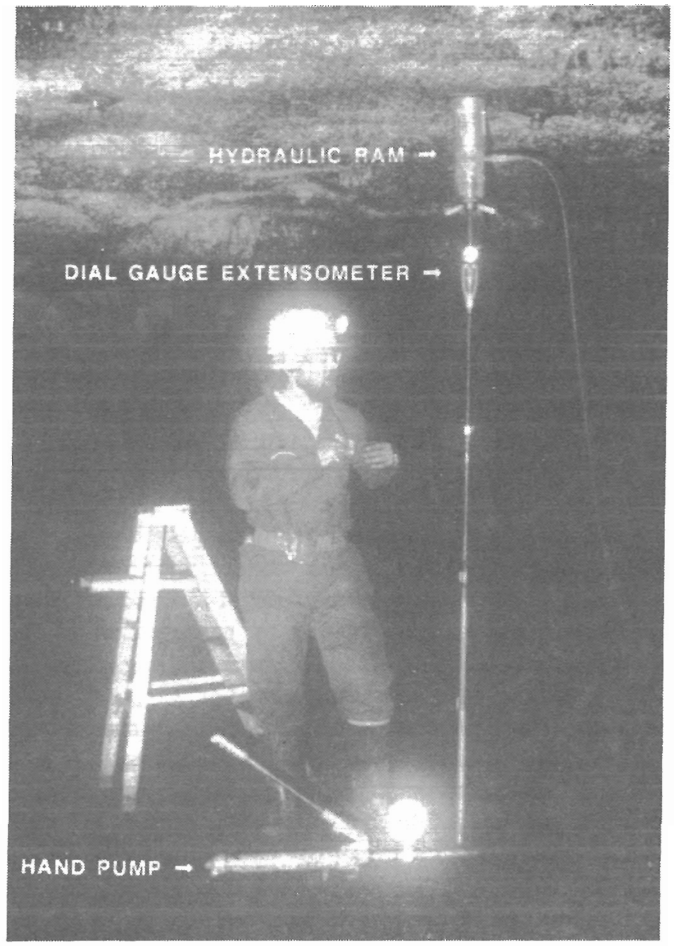

Figure 2.—Testing equipment.

A resin-grouted bolt acquires anchorage capacity from mechanical interlock between the rock-grout and grout-steel interfaces (fig. 3). There is little or no chemical bond between interfaces. The bolt is held in place by the grout acting on irregularities along the length of the borehole wall and the projecting ribs of the steel rebar (*6*, *10*).

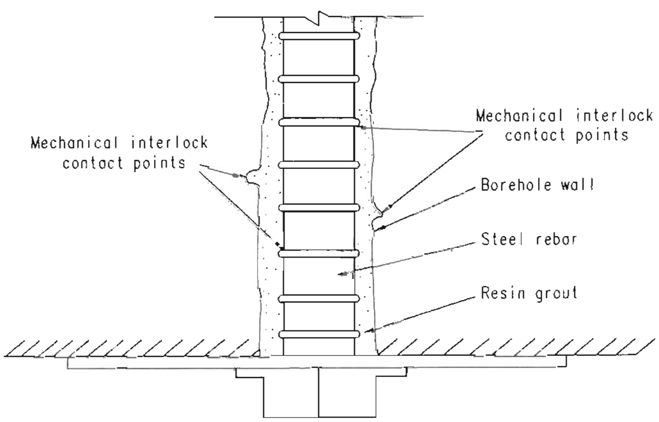

Figure 3.—Resin-grouted mechanical interlock.

During a pull test, shear strain at the rock-grout interface, shear strain at the grout-steel interface, tensile strain of the steel rebar, and elongation of the testing equipment can all contribute to measured deformation. The portion that each strain component adds can become a complicated mechanics problem if the grout anchor starts to slip. Research has shown that for tests conducted in several types of roof rock, *shortly after careful* installation, grout columns 18 in or longer provide sufficient anchorage to cause 0.75-in-diam, SAE Type 40 steel, resin-grouted bolts to experience tensile failure in most cases (*11*).

Two anchorage characteristics that are readily determinable from pull-test data are axial stiffness and yield point. Axial stiffness is the ratio of load to deformation on the straight-line section of the data plot and can be determined by calculating slope of the best-fit line. The higher an axial-stiffness measurement was, the harder it was to pull the bolt head away from the mine roof during the test. Yield point occurs at the load level at which there is a distinct increase in deformation, and the trace of the plot no longer remains linear. A test graph with these characteristics indicated is shown in figure 4.

The pull test is a quick and uncomplicated method to determine anchorage capacity. If a roof bolt has good capacity, then the steel rebar can usually be loaded to failure. If a roof bolt has poor capacity, then low axial stiffness and yield point can be measured.

For this investigation, axial-stiffness measurements were categorized as steady (fig. 5*A*), shifted (fig. 5*B*), or badly shifted (fig. 5*C*). Shifts in the straight-line section of the pull-test graph can be caused by compression of the bearing plate, crushing of the roof rock, settling of the pull collar on the bolt head, grout-anchor slip, and other factors. There were six test bolts with badly shifted axial stiffness that were not included in the evaluation of results.

The interpretation of pull-test graphs is not an exact science, involves subtle changes of data, and can be somewhat subjective. But if sources and influence of experimental error are considered and all data are treated consistently, time-dependent behavior can be effectively evaluated.

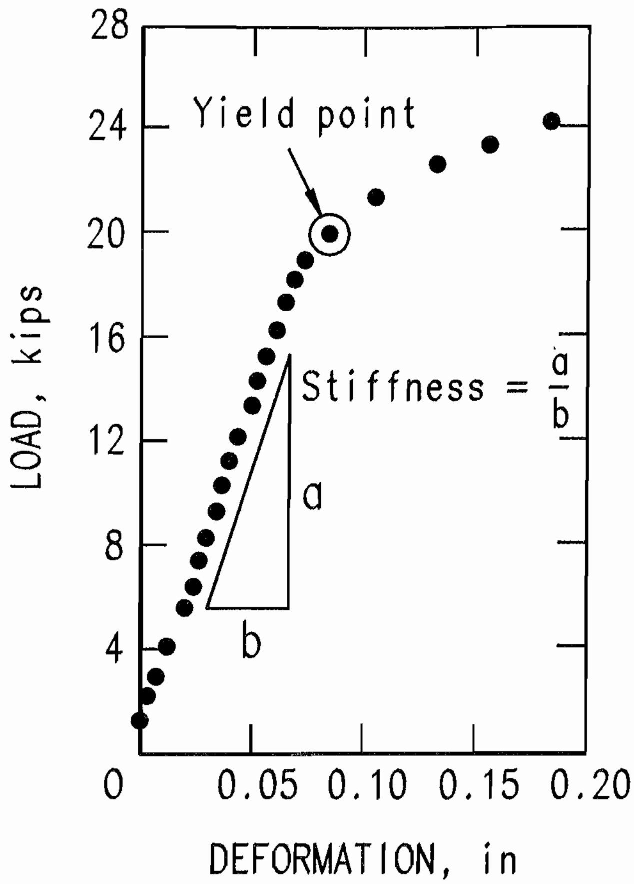

Figure 4.—Pull-test graph showing axial stiffness and yield point.

UNDERGROUND FIELD SITE

The field site for this study was at the Roadside Mine, which is located along U.S. Interstate 70 approximately 15 miles east of Grand Junction, CO (fig. 6). The test bolts were installed in three adjacent crosscuts of the 2 South mains (fig. 7). Pillars in 2 South are 75 ft by 75 ft, rib to rib, and the depth of overburden is 550 ft. The immediate roof is thinly laminated gray shale approximately 10-ft thick (table 1) and has no ground water seeping through.

Because the field site was located in a main entry (designed for long-term stability), this investigation was conducted in a relatively static environment with limited effects from mining-induced bolt stress. There was no observed evidence of room instability or heavy loading on the roof, pillars, or floor during the study. From visual inspection, the roof did not sag and the floor did not heave. There were no roof falls or serious rib sloughage in the area.

Seventy-three 4-ft-long, 0.75-in-diam, Type 40 steel bolts with 48-, 24-, and 18-in grout column lengths were placed in the field-site roof (fig. 8). To obtain the required column length, an equivalent-length grout cartridge was inserted into the borehole; then the rebar, pull collar, and bearing plate were carefully installed according to the manufacturer's specifications. The resin grout had a 20-s set time. Test bolts were placed in addition to required support several months after the field site had been mined.

Twenty-four hours after installation, then again at 3, 6, and 9 months, randomly selected bolts of each column length were subjected to pull tests. At the end of

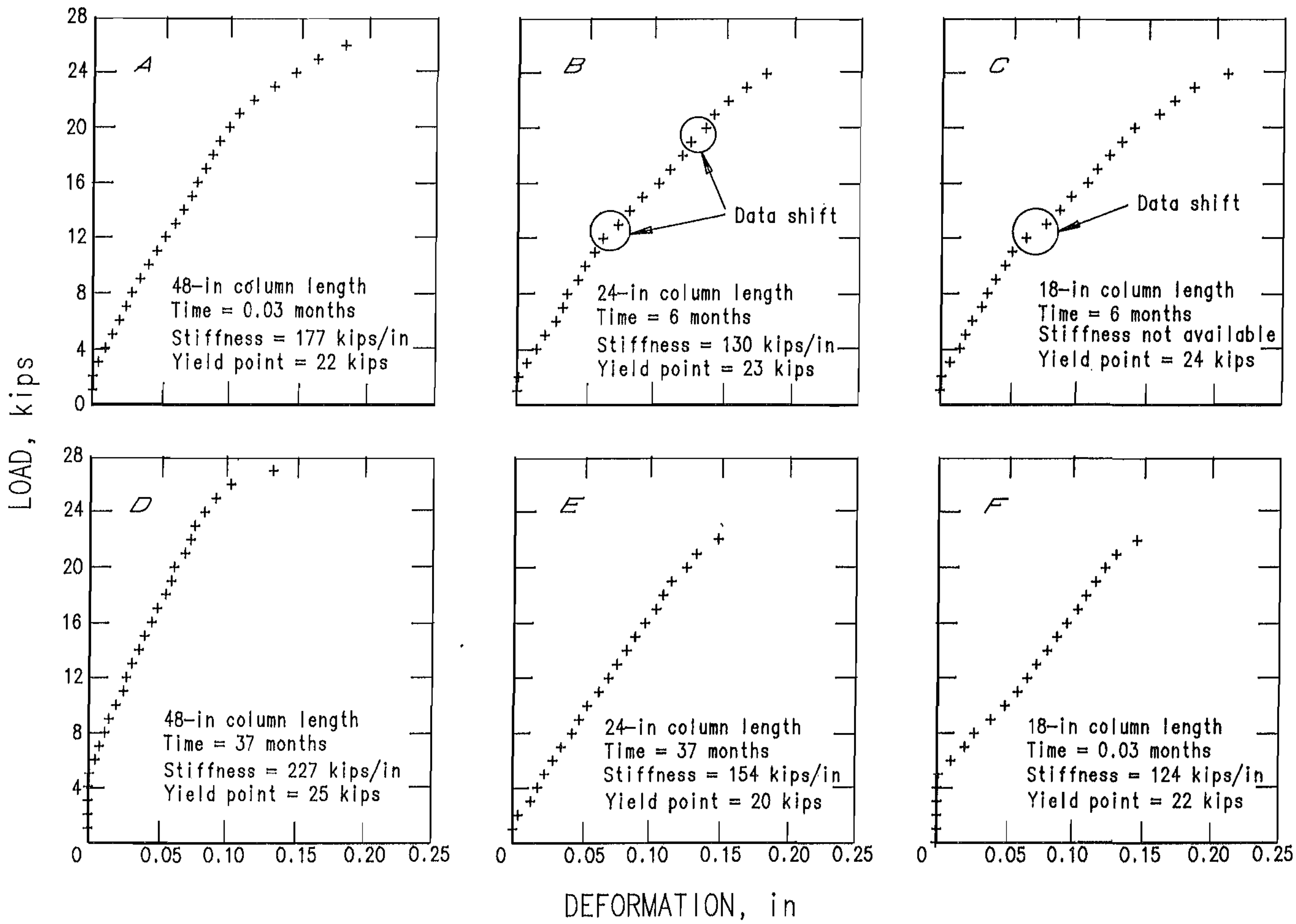

Figure 5.—Pull-test graphs of six typical test bolts. *A*, Bolt 37; *B*, bolt 140; *C*, bolt 10; *D*, bolt 48; *E*, bolt 33; *F*, bolt 109.

9 months, all 18-in-column bolts had been pulled. However, nine 48-in-column and four 24-in-column bolts had not been pulled, and these were tested 37 months after placement. The location and testing sequence is shown in figure 9.

The anchorage characteristics are listed in table 2. Axial stiffness measurements were not adjusted to exclude the effect of the steel rebar and testing equipment, and stiffness is labeled Not available (NA) for bolts that had badly shifted pull-test data. The tests of two bolts were stopped before yield point was reached, and these measurements are also labeled NA.

Table 1.—Rock properties of field-site roof

Property		*Magnitude*
Young's modulus	lb/in^2	1,150,000
Compressive strength	lb/in^2	3,770
Tensile strength	lb/in^2	126
Poisson's ratio		.34
Unit weight	lb/ft^3	154
Water content	pct	2.85

Table 2.—Pull-test results

Bolt	Time, months	Column length, in	Axial stiffness, kips/in	Yield point, kips
37 ...	0.03	48	177	22
38 ...	.03	48	242	19
53 ...	.03	48	120	22
54 ...	.03	48	146	21
147 ..	.03	48	133	25
163 ..	.03	48	145	20
19 ...	.03	24	136	20
20 ...	.03	24	178	21
35 ...	.03	24	121	22
36 ...	.03	24	197	20
127 ..	.03	24	153	19
128 ..	.03	24	135	17
129 ..	.03	24	121	20
1	.03	18	105	20
2	.03	18	115	20
17 ...	.03	18	107	23
109 ..	.03	18	124	22
110 ..	.03	18	123	21
111 ..	.03	18	108	20
125 ..	.03	18	160	20
39 ...	3	48	225	24
52 ...	3	48	141	21
148 ..	3	48	176	22
21 ...	3	24	160	22
34 ...	3	24	109	24
130 ..	3	24	145	21
3	3	18	110	21
112 ..	3	18	108	22
219 ..	3	18	134	21
237 ..	3	18	119	22
255 ..	3	18	103	21
44 ...	6	48	NA	22
45 ...	6	48	243	20
47 ...	6	48	207	24
155 ..	6	48	161	22
156 ..	6	48	207	25
157 ..	6	48	206	22
26 ...	6	24	95	22
27 ...	6	24	143	22
29 ...	6	24	172	20
138 ..	6	24	162	21
139 ..	6	24	99	20
140 ..	6	24	130	23
8	6	18	NA	22
9	6	18	100	24
10 ...	6	18	NA	24
119 ..	6	18	127	23
120 ..	6	18	96	22
121 ..	6	18	100	22
150 ..	9	48	157	19
152 ..	9	48	187	21
154 ..	9	48	171	21
133 ..	9	24	133	NA
134 ..	9	24	124	19
135 ..	9	24	101	16
136 ..	9	24	171	20
137 ..	9	24	151	19
114 ..	9	18	138	20
115 ..	9	18	79	NA
116 ..	9	18	112	21
40 ...	37	48	258	21
41 ...	37	48	204	21
42 ...	37	48	127	25
43 ...	37	48	216	22
46 ...	37	48	261	28
48 ...	37	48	227	25
49 ...	37	48	NA	21
50 ...	37	48	NA	24
61 ...	37	48	NA	23
30 ...	37	24	126	18
32 ...	37	24	145	22
33 ...	37	24	154	20
87 ...	37	24	106	20

NA Not available.

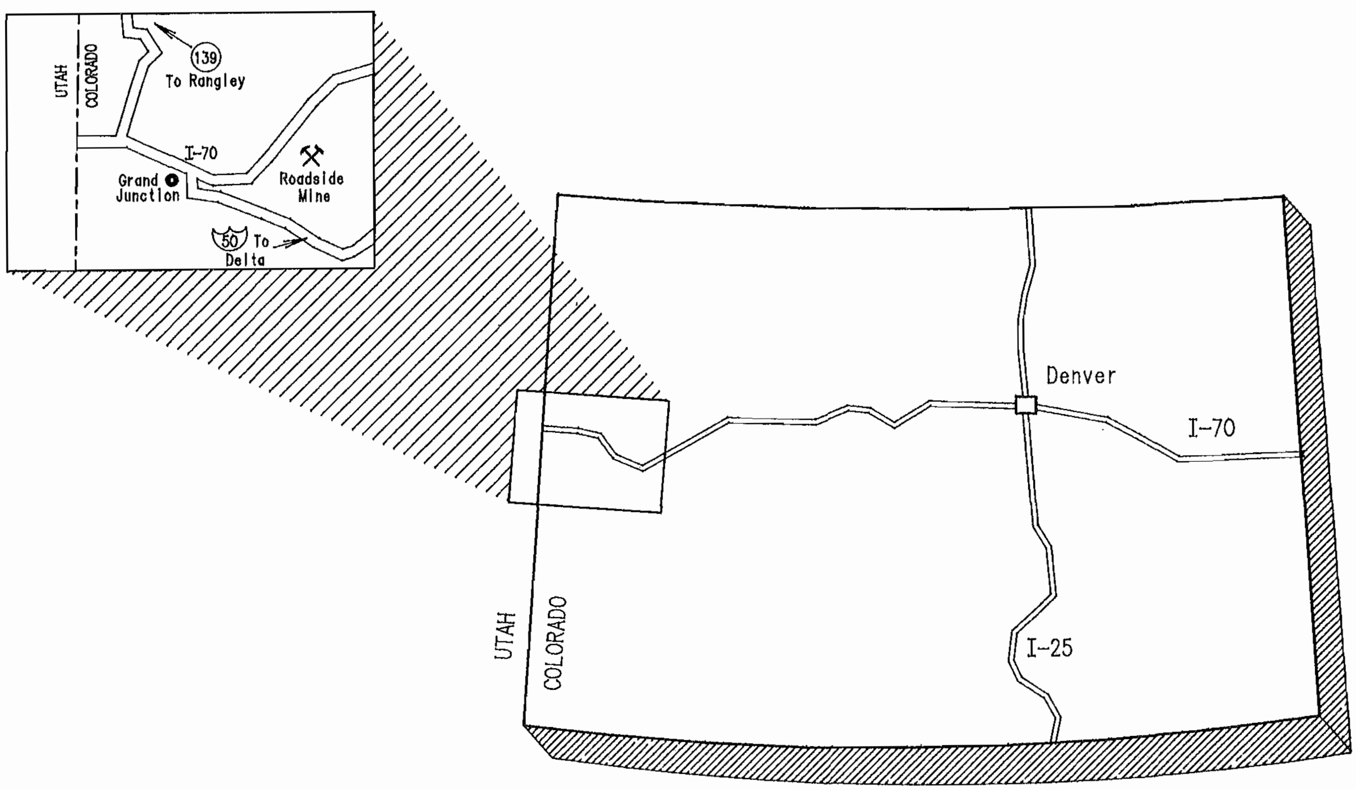

Figure 6.— Field-site mine location.

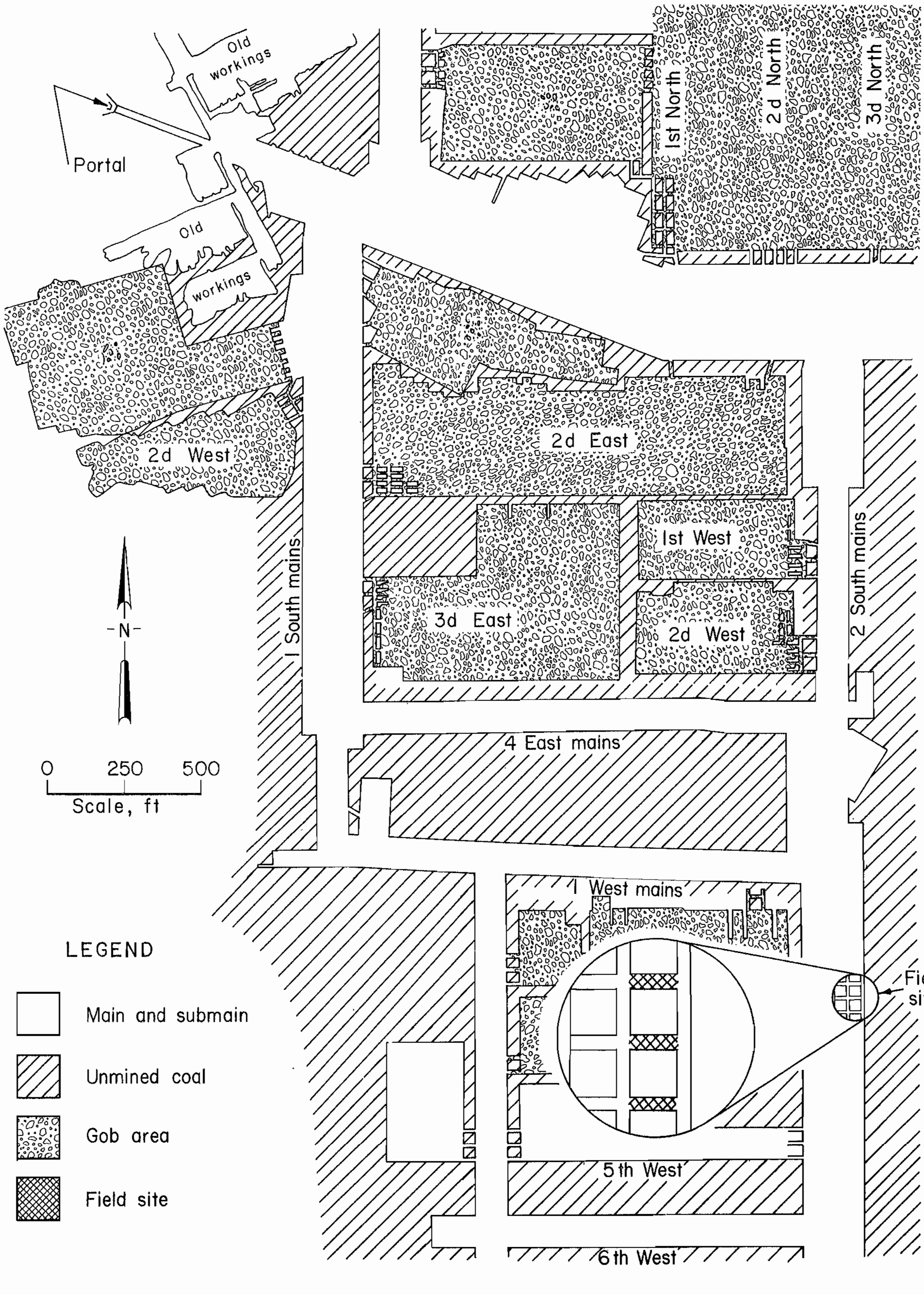

Figure 7.—Field-site mine map.

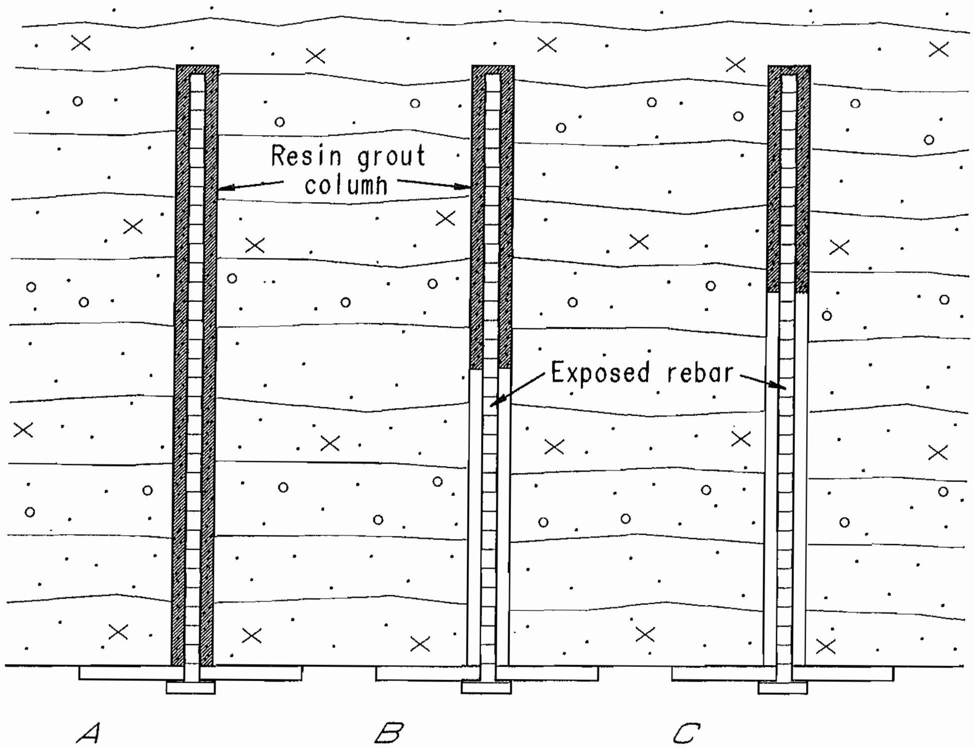

Figure 8.—Test-bolt column lengths. ***A*, 48 in; *B*, 24 in; *C*, 18 in.**

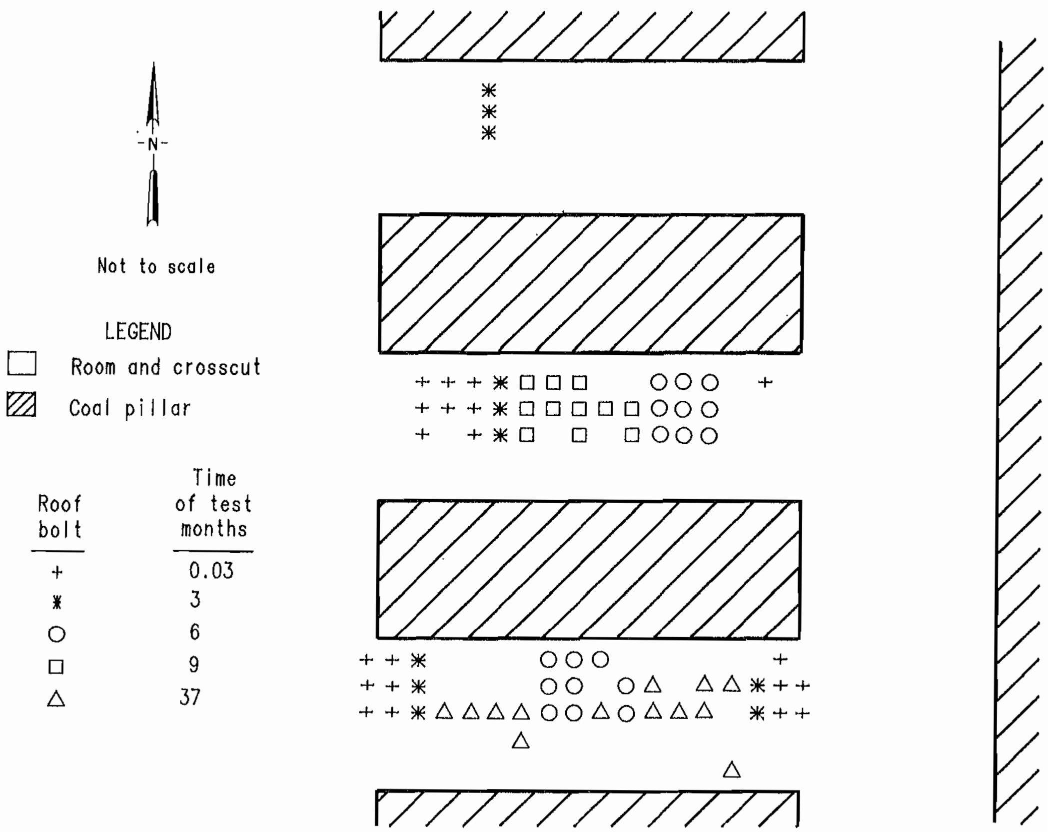

Figure 9.—Test-bolt location and pulling sequence.

PRESENTATION AND EVALUATION OF RESULTS

To evaluate time effects on the roof bolts, pull-test data were grouped into 28 sets according to anchorage characteristic, grout column length, and time of test. For example, set one is the axial-stiffness measurements of all bolts with 48-in grout columns tested the day after installation; set two is the yield-point measurements of all bolts with 48-in grout columns tested the day after installation; set three is the axial-stiffness measurements of all bolts with 48-in grout columns tested 3 months after installation, and so forth. Next, the statistical mean, range, and standard deviation of each set was calculated (table 3). Average sample size is five bolts. Mean axial stiffness and yield point were then plotted against time (figs. 10-11). Combined column length axial-stiffness- and yield-point-versus-time graphs are shown in figure 12.

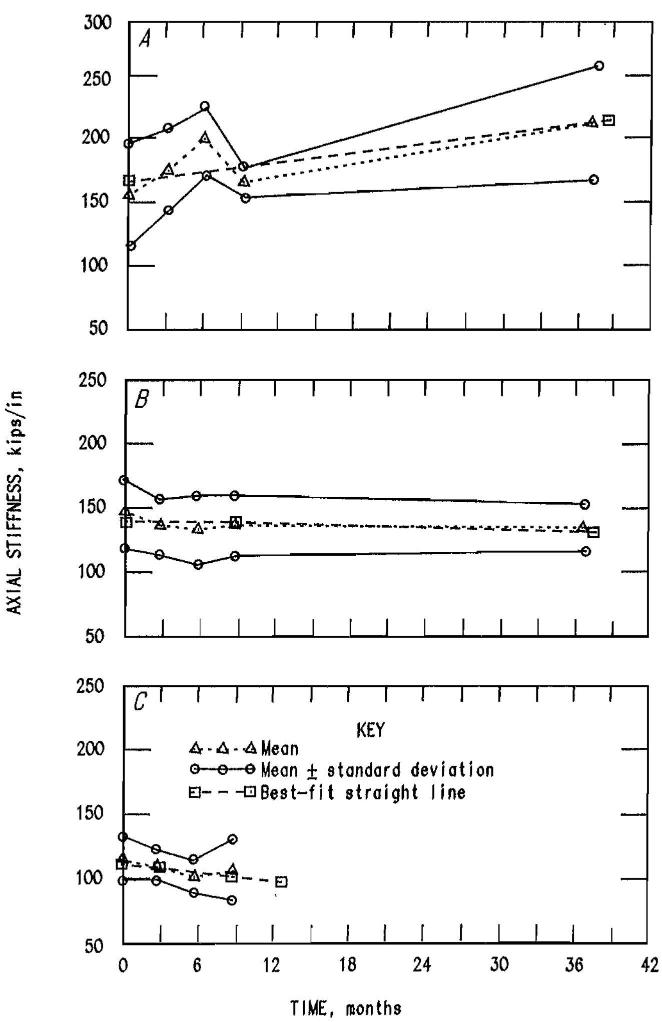

Figure 10.—Axial-stiffness-versus-time graphs with standard deviations and best-fit straight lines. *A*, 48 in; *B*, 24 in; *C*, 18 in.

Examination of figures 10, 11, and 12 establishes that anchorage capacity of the test bolts remained high throughout the study. Of 67 total axial-stiffness measurements, only four were less than 100 kips/in (table 2), and mean axial stiffness never fell below 106 kips/in for all data sets. Considering that a rod with 100-kips/in stiffness

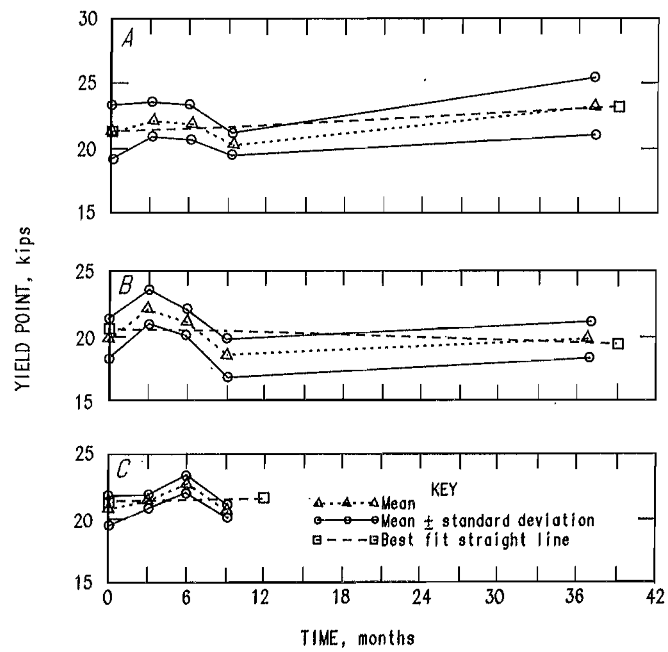

Figure 11.—Yield-point-versus-time graphs with standard deviations and best-fit straight lines. *A*, 48 in; *B*, 24 in; *C*, 18 in.

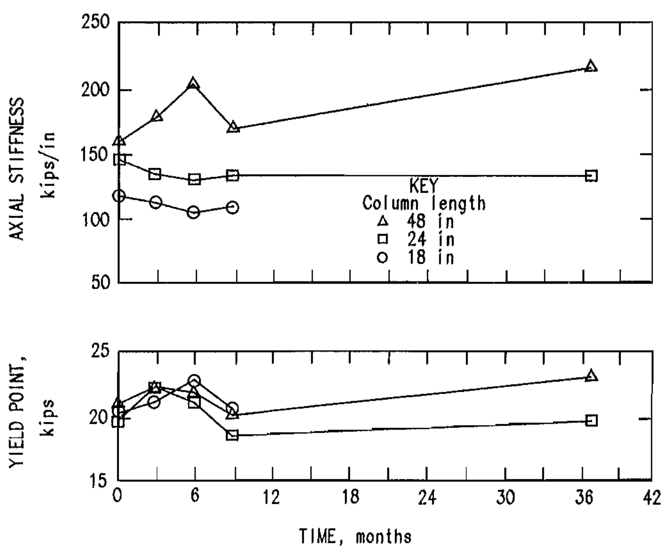

Figure 12.—Combined column length axial-stiffness-versus-time and yield-point-versus-time graphs.

requires 1,000-lbf to cause 0.01-in elongation, it is clear that the bolts remained securely anchored in the mine roof. Also, of 71 yield-point measurements, only 2 were less than 17.7 kips, the theoretical yield of the steel rebar. Mean yield point never fell below 18.5 kips for all data sets. There is no evidence of measurable deterioration of anchorage capacity for all column lengths.

Table 3.—Statistical summary for pull-test data sets

Time, months	Axial stiffness, kips/in			Yield point, kips		
	Mean	Range boundary	Std dev	Mean	Range boundary	Std dev
			48-in COLUMN LENGTH			
0.03 ..	161	120,242	40	21.5	19,25	1.9
3	181	141,225	34	22.3	21,24	1.3
6	205	161,243	26	22.5	20,25	1.6
9	172	157,187	12	20.3	19,21	.9
37 ...	216	127,261	45	23.3	21,28	2.3
			24-in COLUMN LENGTH			
0.03 ..	149	121,197	27	19.9	17,22	1.5
3	138	109,160	21	22.3	21,24	1.3
6	134	95,172	29	21.3	20,23	1.1
9	136	101,171	24	18.5	16,20	1.5
37 ...	133	106,154	19	20.0	18,22	1.4
			18-in COLUMN LENGTH			
0.03 ..	120	105,160	18	20.9	20,23	1.1
3	115	103,134	11	21.4	21,22	.5
6	106	96,127	12	22.8	22,24	.9
9	110	79,138	24	20.5	20,21	.5
37 ...	NA	NA	NA	NA	NA	NA

NA Not available.

It can be seen on table 3 that some of the data sets had large ranges and standard deviations. But there are numerous parameters associated with in situ pull testing that can contribute to experimental error (*12*). These parameters include roof-bolt installation procedures, variation of rock lithology, cracks and voids in the roof, placement of testing equipment, and execution of test. Like the axial-stiffness and yield-point measurement plots, the standard-deviation plots of figures 10 and 11 remained above acceptable values at all times throughout the study. Improvement of installation procedures and application of a more consistent pull-test technique is necessary and would probably improve the data scatter of similar investigations.

As calculated, axial stiffness is affected by the grout column anchor, steel rebar, and testing equipment. It is indicated in figure 12 that mean axial-stiffness measurements are clustered around a distinct magnitude for each grout column length: 185 kips/in for 48-in columns, 135 kips/in for 24-in columns, and 110 kips/in for 18-in columns. There is a difference in magnitudes because test bolts with 48-in columns have very firm anchorage, and the length of exposed rebar that can readily stretch is only about 2 in. On the other extreme, bolts with relatively short, 18-in columns are more likely to have anchorage slip, and the length of exposed rebar that can readily stretch is about 30 in. Lower stiffness can be desirable if yield is needed for ground control purposes. The pull-test reaction of bolts with 24-in columns falls somewhere in between. In all cases, the effect of the testing equipment is constant.

CONCLUSIONS

Test bolts with 18-in grout column lengths exhibited no measurable loss of anchorage capacity for 9 months. Test bolts with 48- and 24-in grout column lengths exhibited no measurable loss of anchorage capacity for 37 months. These results were established from the evaluation of axial-stiffness and yield-point measurements over time.

It is important to note that this investigation was conducted at a single underground field site, and these conclusions are site specific. Although some extrapolation can be made, careful consideration should be given if using the results for roof-control design in dissimilar ground conditions and operating settings, especially underground workings subjected to excessive mining stress.

REFERENCES

1. Scott, J. J. Roof Bolting—A Sophisticated Art. Coal, v. 26, No. 8, Aug. 1989, pp. 59-69.

2. Panek, L. A. The Combined Effects of Friction and Suspension in Bolting Bedded Mine Roof. BuMines RI 6139, 1962, 31 pp.

3. Karabin, G. J., Jr., and W. J. Debevec. Comparative Evaluation of Conventional and Resin Bolting Systems. MESA IR 1033, 1976, 22 pp.; available from Natl. Mine Health and Saf. Acad., Beckley, WV.

4. Kwitowski, A. J., and L. V. Wade. Reinforcement Mechanisms of Untensioned Full-Column Resin Bolts. BuMines RI 8439, 1980, 37 pp.

5. Ballivy, G., and A. Martin. The Dimensioning of Grouted Anchors. Paper in proceedings of The International Symposium on Rock Bolting. A. A. Balkema, 1984, pp. 353-365.

6. Serbousek, M. O., and S. P. Signer. Load Transfer Mechanics in Fully Grouted Roof Bolts. Paper in Proceedings of Fourth Conference on Ground Control in Mining. WV Univ., Morgantown, WV, 1985, pp. 32-40.

REFERENCES—Continued

7. Cincilla, W. A., and S. C. Tadolini. Effects of Bearing Plates and Grout-Column Length on Resin-Bolt Performance. Paper in Proceedings of Symposium on Engineering Health and Safety in Coal Mining. Soc. Min. Eng., Inc., 1986, pp. 60-74.

8. Gerrard, C. Rock Bolting in Theory. Paper in Proceedings of The International Symposium on Rock Bolting. A. A. Balkema, 1984, pp. 3-32.

9. International Society for Rock Mechanics. Committee on Field Tests, Suggested Method for Rock Anchorage Testing. Int. J. Rock Mech. and Min. Sci., v. 22, No. 2, 1985, pp. 71-83.

10. Tadolini, S. C. Anchorage Capacities in Thick Coal Roofs. BuMines IC 9058, 1986, 13 pp.

11. Cincilla, W. A. Determination of Effective Column Lengths for Resin-Grouted Roof Bolts. Paper in Proceedings of Fifth Conference on Ground Control in Mining. WV Univ., Morgantown, WV, 1986, pp. 6-12.

12. Snyder, V. W., J. C. Gerdeen, and G. L. Viegelahn. Factors Governing the Effectiveness of Roof Bolting Systems Using Fully Resin-Grouted Nontensioned Bolts. Paper in Proceedings of 20th U.S. Symposium on Rock Mechanics. Univ. TX at Austin, 1979, pp. 607-613.

☆ U.S. GPO: 1991—511-010/42,029

INT.BU.OF MINES,PGH.,PA 29440